Universities, Public Research, and Evolutionary Economic Geography

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Abstract

Evolutionary Economic Geography (EEG) has, thus far, neglected the contribution of universities to innovation processes in its emerging theoretical explanations of territorial economic change. This paper begins to address this conceptual gap by outlining a perspective on the ways in which universities, as organizations with institutional features and functions that are distinctive to those of firms, can enhance the adaptive capacity of national or regional economies. The argument developed is based on a complexity theory view of system self-transformation and supports greater attention to this framework in a pluralistic EEG.

Keywords Universities, evolutionary economic geography, complex adaptive systems, regional adaptive capacity.

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Introduction

The previous decade has seen the development of approaches in economic geography in which evolutionary thinking has been placed more centrally (Boschma and Martin 2010). This new evolutionary economic geography (EEG) has sought to position itself as a distinct paradigm from existing approaches based on neoclassical or institutional theories (Boschma and Frenken 2006). In this, EEG has largely eschewed the concept of innovation systems as an analytical approach in favor of a renewed emphasis on populations of firms as the key constituents and drivers of change in a regional economy. As a result, the parallel role of non-firm organizations such as universities, public research institutes, and various other intermediary actors have largely been neglected (Asheim *et al.* 2013; Tanner 2014). This paper will focus on how universities, as one particular type of this non-firm organization with distinctive institutional features and a widely-recognized role in regional innovation, can be incorporated into EEG.

The paper addresses this question through an argument with three interrelated strands. First, while EEG has ushered in a welcome recognition of the role of firms as principal agents of economic change, this has led to a relatively narrow view of innovation as a dynamic that is predominately driven by competition in market environments. This therefore overlooks other possible forms of innovation that relate to more exploratory scientific and technological development characteristically performed by universities (alongside other public research institutes and larger firms with R&D capabilities). A fully-developed evolutionary theory of processes of new path creation and regional adaptation, it is contended, requires consideration of both of these modes of innovation and their interplay. Second, universities also differ from firms in a number of important institutional characteristics relating to their organizational structure, external relationships, and receipt of public funding to perform basic research. This institutional diversity within the economic system, not just amongst firms with varying routines but also between organizations of fundamentally different types, is crucial to evolutionary processes. In particular, it will be argued that the distinctive features of research universities means that their presence can enhance the long-term adaptive capacity of national and regional economies. Third, the incorporation of these arguments into EEG supports the use of a complex adaptive systems framework (Martin and Sunley 2007). This can better accommodate the elements of non-market innovation and institutional diversity than the variants on generalized Darwinism that have been the main theoretical approach in EEG. Accordingly, the paper adopts and explores the proposal by Metcalfe (2010, p.7) that "universities and businesses ... are coupled sub systems of a complex adaptive system".

These thematic strands are developed across four sections. The first provides a brief overview of EEG, focusing on differences between selection and system self-transformation explanations of change. The second argues that the contribution of universities to evolutionary processes in regional economies should be understood in complex adaptive system frameworks. The third outlines the multidimensional concept of system adaptive capacity at different levels, and then discusses how universities can be a source of this adaptive capacity in territorial economies. The conclusion summarizes the key arguments of the paper and how they may inform future research.

Evolutionary Economic Geography

Even within recent efforts to formulate EEG as a distinct theoretical project, several approaches have been utilised to study the core phenomena of regional economic change and uneven development. This works against concise statements of an evolutionary position in economic geography that are fully coherent or comprehensive. It is possible, however, to identify some shared conceptual propositions and concerns that delineate the main currents of these new perspectives. This brief overview will touch on all three of the possible theoretical frameworks identified by Boschma and Martin (2010): Path Dependence Theory, Generalized Darwinism, and Complexity Theory. The third of these, whilst being the least developed in economic geography, is of particular significance to the wider argument, and will be given special emphasis at the end of the section.

Perhaps the common starting point for EEG, as with evolutionary economics more generally (Nelson and Winter 1982), is a rejection of the static equilibrium analysis of neoclassical economics (Boschma and Frenken 2006). Instead, evolutionary approaches are concerned with theoretical models and empirical research that focus on processes through which dynamic structural and technological change occur in the economy; including innovation, entrepreneurship, industry growth and decline, and clustering (Essletzbichler and Rigby 2007; Boschma and Frenken 2011; Ter Wal and Boschma 2011). The possible courses of this change are, however, at any time circumscribed by the inherited context of dominant technologies, organizational forms, and shared institutions or conventions that shape economic behavior within a particular industrial and territorial context (David 1994; Storper 1995). This sense of the historical contingency of future development underlies the key evolutionary notion of 'path dependency', which economic geographers have interpreted as having a strong place dimension based on the localized nature of constituent mechanisms such as increasing returns and external economies (Martin and Sunley 2006). Path dependency has been an established concept in institutional and political economy approaches to economic geography that preceded the recent 'evolutionary turn'; in particular helping to explain the 'lock-in' of some regional economies to outmoded industrial or technologies trajectories (Grabher 1993). More recently, however, Martin (2010) has criticized the use of the path dependency concept in economic geography for concentrating on these forces towards continuity and stasis over forces to change. He proposes that a genuinely evolutionary understanding of economic geography needs to develop a new model that incorporates path dependence as a 'dynamic process' as well as 'movement to a stable state'.

One central strand of EEG addresses these sources of dynamism by evoking the general evolutionary principles of variety, selection, and heredity. A key point of departure for this work is that it follows Nelson and Winter (1982) in taking firm-level routines, and not shared regional institutions (e.g. social conventions, formal/informal rules), as the primary medium of contingency in action over time, and therefore, a main analytical building block of their theories[1]. Collective institutions that condition (without fully determining) action in a regional environment still feature, but are conceptualized as an emergent outcome of micro-level processes; co-evolving with organizational routines in the development of new industrial and technological paths (Boschma and Frenken 2006; 2009). Routines are understood to be organization-specific patterns of behavior, and therefore the source of heterogeneity between firms that (even within the same industry or locality) inevitably have different capabilities, network positions, and operating procedures (Boschma and Frenken 2006; Essletzbichler and Rigby 2007). This variety is integral to the selection mechanism by which firms with 'fitter' (more efficient or adaptable) routines gain a competitive advantage that allows them to survive and grow. Hence, this allows generalized Darwinian approaches in EEG to frame regional economies as a 'population' of firms in a competitive market and

[1] This has been contested from a political economy perspective on EEG, which argues the micro-level focus on firms will lead to wider processes of uneven capital accumulation, labour relations, and state intervention in shaping regional economic change being obscured (MacKinnon *et al.*, 2009; Pike *et al.*, 2009).

institutional environment, and to analyze processes of change in this population through general evolutionary principles drawn more or less directly from biology - such as variety, fitness, selection, inheritance and adaptation (Essletzbichler and Rigby 2007; Hodgson 2009; Boschma and Martin 2010). As Essletzbichler and Rigby (2007, p.552) write:

> dynamic processes that jointly influence the behaviour of firms and the market environment in which they operate … can be considered evolutionary in the sense that the capitalist economy consists of competing agents that differ in at least some characteristics (heterogeneity) that influence individual prospects for economic growth (selection), and that change more or less slowly over time (heredity), both shaping and being shaped by the environment within which future competition unfolds.

In this framework, innovation is understood as a response to the uncertainty faced by firms in this competitive environment, and takes the form of continuous experimentation and search for new knowledge that can lead to fitter routines (Essletzbichler and Rigby 2005; 2007; Martin 2010). This is not a wholly internal process of organizational learning, but draws on knowledge externalities that, in settings where geographically-bounded spillovers between firms are crucial, become a property of cluster environments and a key factor explaining agglomeration in EEG (Boschma and Lambooy 1999; Boschma and Frenken 2006). These externalities can lead to the formation of a shared regional knowledge base and other institutional factors underlying localized learning which, by encouraging certain firm routines over others, forms part of territorial selection environments (Boschma 2004; Malmberg and Maskell 2010). Others have emphasized the transmission and inheritance of routines between firms through spin-off enterprise formation and labor mobility (Klepper 2010; Stam 2010; Ter Wal and Boschma 2011). Because these mechanisms are typically localized, this process of routine inheritance and replication can, even in the absence of transaction-based agglomeration economies, support the emergence of clusters of firms in the same region with related capabilities (Boschma and Frenken 2011). A related strand of EEG has studied networks between firms as a complementary mechanism of knowledge or routine diffusion. Due to the potential for forms of relational proximity to substitute for co-location within clusters, this networking can occur on a wider geographical scale, and non-local knowledge is recognized as a source of novelty that helps firms avoid lock-in to regional technology paths (Glückler 2007; Boschma and Frenken 2010). The developing EEG perspective on networks emphasizes that the formation of these relational ties is itself a selective and dynamic evolutionary process (Glückler 2007), and network structures are shaped by the varied capabilities of the firms involved that determine their attractiveness as a partner and capacity to absorb external knowledge (Giuliani 2010; Ter Wal and Boschma 2011).

Hence, these different means of selection amongst inherently varied firm routines is seen as an endogenous source of change within regional economies. An alternative conceptual understanding of this dynamism has been proposed by Martin and Sunley (2007) based on theories of complex systems, although this has yet to be taken up as widely as path dependence or generalized Darwinism frameworks (Boschma and Martin 2010). Complexity theory, while having some similar elements to these other evolutionary approaches[2], modifies the metaphor for understanding the economy from the population of agents to a complex adaptive system composed of distributed but connected components at various interacting scales. In its core concept of self-organization, complexity theory shares with the EEG approach outlined above a broad understanding of meso-level structures (e.g. clusters) as

[2] Cooke (2012) in particular demonstrates the complementary nature of evolutionary concepts including path dependency, related variety, co-evolution, emergence, and complex adaptive systems within regional economic analysis.

being emergent outcomes of cumulative, reinforcing micro-scale processes (Garnsey 1998; Martin and Sunley 2007; Staber 2010). In complexity theory, however, the emergence and ordering of these structures is not explained by selection and inheritance of routines amongst competing firms (Foster 1997), but through co-evolution and adaptation of system components from the spontaneous interactions and non-linear feedback dynamics between them (Arthur 1999). Various properties of complex adaptive systems, including openness to their environment with no fixed boundaries, high-levels of connectivity between distributed components, and their 'far-from-equilibrium' nature, means that the structure of the economy is mainly understood to evolve through (still path-dependent) processes of self-transformation (McGlade and Garnsey 2006; Martin and Sunley 2007; Lemay and Sá 2012). As Martin and Sunley (2007, p.591-592) argue:

> [T]he main difference between complexity economics and neo-Darwinian views of economic evolution appears to rest on the relative importance of system self-transformation relative to selection. ... [O]ur analysis of the evolution of an economic landscape should look at both types of change and should not always assume that selection is operative.

One important distinction for this complexity perspective is that, in social systems such as the economy, the ongoing growth of knowledge is an important driver of self-transformation (Potts 2001; Metcalfe and Ramlogan 2005; Antonelli 2009). Foster (1997, p.444) writes:

> Once we abandon biological analogy in favour of an economic self-organization approach ... we are no longer interested in the microscopic details of selection

> mechanisms, but in the endogenous tendency for acquired knowledge and skills to interact to create increases in economic organization and complexity.

The socially distributed nature of knowledge means that its growth is a source of constant 'restlessness' in capitalism that leads to economic evolution through the restructuring of connections within complex adaptive systems (Metcalfe and Ramlogan 2005; Martin and Sunley 2007). Presented in this way, there is a risk that differences between selection and self-transformation perspectives are exaggerated. For instance, markets are important in evolutionary economics both as elements of selection environments, and as Potts (2001) argues, mechanisms for the structuring of knowledge. Indeed more recently Martin and Sunley (2015) have sought to bring neo-Darwinian and complexity theory approaches closer together. However, the following section will show that framing them as alternative explanations of economic change is a useful heuristic for positioning universities in EEG.

Universities in regional economic evolution

Explicit discussion of universities is almost entirely absent from the various endeavors to construct a theoretical basis for EEG discussed above. However, universities are recognized as key actors in the large interdisciplinary literature on innovation, and greater attention to them clearly has potential to contribute to the need, identified by Martin and Sunley (2006), for EEG to increase its understanding of processes underlying regional path creation and adaptation. This section will refer to previous research to explore how universities may be incorporated into EEG conceptual schemes. The diversity of relations that universities form with other economic agents through both market and non-market based mechanisms, it is argued, supports use of a complexity and system-self-transformation framework.

One possible way in which universities could be approached within EEG is to treat them as a source of new knowledge that is exogenous to the economic system. This could be seen as the current default theoretical position in which universities are not considered alongside firms. Most research on knowledge-based regional development, however, recognizes universities as an integral part of local innovation system processes, and therefore as basically endogenous to the economy. For instance, the literature on academic knowledge spillovers has used econometric analysis to demonstrate that this form of externality is localized within a given region and can account for the concentration of high-technology industry around strong research universities (e.g. Anselin *et al.* 1997). Theoretically, this approach aligns with the analytical use of knowledge spillovers as an explanation of agglomeration in EEG (Boschma and Frenken 2006). However, knowledge spillover studies have significant conceptual and methodological limitations (Uyarra 2010). As Breschi and Lissoni (2001) argue, the main knowledge production function approach of relating regional innovation inputs (e.g. R&D) to outputs (e.g. patents) can only indicate the presence of some kind of local knowledge spillover and not the mechanisms through which this occurs, leaving unchallenged the received notion of knowledge as a public good that is nevertheless geographically bounded because of its inherently tacit nature.

Primarily qualitative case studies have also reflected the role of universities when tracing the development of successful high-technology clusters, sometimes employing concepts such as complex systems and path dependency (Garnsey 1998; Garnsey and Lawton Smith 1998; Kenney and von Burg 1999; Gertler and Vinodrai 2009). An evolutionary perspective here, however, helps caution that while the presence of strong research universities may be an important factor in the development of high-technology milieus, it is not alone a sufficient condition (Braunerhjelm 2008). Studies comparing the emergence of high-technology industry in Silicon Valley and Route 128 (Kenney and von Burg 1999) and around Cambridge and Oxford in southern England (Garnsey and Lawton Smith 1998) have shown that in both cases multiple local industrial and institutional factors with cumulative self-reinforcing effects, including the formative role of key early events or actors, have meant that the rival clusters grew along varying paths, despite having leading universities in common (also Garnsey 1998).

These studies address the criticism commonly leveled at knowledge spillover methodologies by uncovering some of the attendant mechanisms. Two of the main forms these take – academic spin-off enterprises and inter-organizational labor mobility - are broadly equivalent with those that EEG emphasize as processes through which routines are transmitted between firms in clusters. Enterprises spun-off directly or indirectly from universities have been a means of technology transfer since at least the mid-twentieth century (e.g. see Kenney and Von Berg 1999 on Silicon Valley), but increasing importance has been attached to them in recent decades as a vehicle for commercializing academic research (Uyarra 2010). Research on successful clusters in the UK has indicated that patterns of repeated spin-offs from universities can have significant cumulative development impacts by begetting other second-generation firm formation and helping to cultivate specialized labor markets (Garnsey and Heffernan 2005; Lawton Smith *et al.* 2008). Related to spin-off firms are the mobility of research staff and graduate students. Employment mobility, more generally, is established as a means of inter-firm knowledge transfer in regions with developed labor markets for scientists and engineers (Almedia and Kogut 1999). Few studies have, however, looked specifically at the movement of academic staff into local industry (Crespi *et al.* 2007)[3]. An

[3] Instead, other research has indicated that in high-technology agglomerations, the attraction of scientific expertise from around the world is perhaps more important than recruitment directly from

exception to this lacuna has been Zucker and Darby's (1996; Zucker *et al.* 1998) work on the formation of the biotechnology industry in the USA, which documents how an elite group of 'star scientists' were crucial in spreading knowledge from experimental breakthroughs into nearby firms. However, this transference often did not involve full-time moves, but was achieved through joint appointments and other shared employment arrangements that allowed individual scientists to retain their university membership whilst assuming a brokerage role with industry. This supports the argument of Breschi and Lissoni (2001) that localized knowledge spillovers are not public goods within a social environment defined by spatial proximity to a university, but occur through more selective market transactions that shape the movement of labor and intellectual property.

> [S]tar scientists are not simply located in the same geographic area with biotech firms, but in fact are frequently deeply involved in their operations as principals, employees, or consultants. … [W]hat might appear … as geographically localized external economies for enterprises located near university stars turn out to exist only for that much smaller set of enterprises which are linked to particular star professors by contract or ownership – that is, by market exchange. (Zucker *et al.* 1998, p.66).

In this case, first-hand awareness of new discoveries in biotechnology and related highly-specialized research techniques was clearly essential for the scientists in question (Zucker and Darby 1996). However, the wider value of (non-star scientist) labor mobility from universities may relate less to transference of this specific 'propositional knowledge' than to

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local universities - although these universities may be important in initially bringing this international talent to the area (Casper and Karamanos 2003; Saxenian 2006; Trippl 2013).

more general advanced know-how and skills embodied in the researcher that can expand the problem-solving routines of the recipient firm (Zellner 2003).

Scientific labor mobility, whether involving permanent or temporary moves between organizations, can facilitate another means of knowledge exchange: formal research collaborations with firms (Muscio 2013; Trippl 2013). This mechanism has been investigated in empirical work that uses data on co-publications or related-patents between individuals in different organizations as an indicator of research collaborations and analyzes the geographic patterns and evolution of the resultant networks (e.g. Ponds *et al.* 2007; Breschi and Lissoni 2009). Firms may pursue research collaborations with universities to, in evolutionary economics terms, search for and access external knowledge in technological fields that are different to but complement their core capabilities (Perkmann and Walsh 2007). While the formation of academic spin-off firms and shared employment arrangements are likely to occur in relative geography proximity to the parent institution where relocation of personnel is unnecessary (Zucker *et al.* 1998; Breschi and Lissoni 2009), research collaborations are not considered subject to such geographic constraints (Ponds *et al.* 2010): leading research universities and larger firms with internal R&D capability, in particular, are more likely to seek collaborations and maintain networks with partners who hold the relevant knowledge wherever they are based (Laursen *et al.* 2011; Muscio 2013). Hence, academic-industry research collaborations have featured in recent economic geography research testing the possibility of knowledge spillovers taking place through networks that are not geographically localized, but rely on relational forms of cognitive or institutional/organizational proximity (Ponds *et al.* 2007; D'Este *et al.* 2013).

This emphasis on the varied nature and geography of the active mechanisms through which universities contribute to regional innovation processes can be extended by reference to the wider literature on academic-industry relationships, which identifies other distinct but overlapping forms of linkage - including licensing, consultancy, and informal network interactions (Perkmann *et al.* 2013). A feature of many of these forms of engagement, evident in the discussion of research collaborations and labor mobility above, is their significance lies less in being a medium of transferring knowledge capital from university to industry than a means of relational network formation that can facilitate reciprocal patterns of knowledge exchange within interactive and non-linear innovation processes (Perkmann and Walsh 2007). Despite the attention paid to commercialization in the literature as a direct and measurable source of economic impacts from university research, surveys of academics from across different fields have shown that often less visible forms of engagement (e.g. contract research, consultancy, networking) are in general more widely practiced (Hughes and Kitson 2012; Goddard and Vallance 2013)[4]. Complementary research from the perspective of industry has shown that the most important sources of academic research findings used by firms to support innovation include ‘open science’ channels such as publications and public meetings (Cohen *et al.* 2002). Howells *et al.* (2012) also find that informal contacts and formal collaborations are mutually reinforcing in settings characterized by complex multi-agent networks rather than simple dyadic linkages. Taken together, this evidence indicates that universities are linked to non-academic actors through a multitude of diverse relationships, engagement processes, and other types of ‘hidden connections’ (Hughes and Kitson 2012).

[4] Evidence for the economic effectiveness of this growing investment in commercialization activities, measured by financial returns to universities, is also limited beyond results for a small number of leading research institutions (see Uyarra 2010).

In light of this, it is pertinent to return to the preceding discussion and consider whether a primary focus on selection or system self-transformation, the two explanations of change identified by Martin and Sunley (2007), is a stronger basis for bringing universities into EEG frameworks. Clearly selection processes have an important role in determining which parts of the diverse knowledge generated through academic research (as a source of variety in the economic system) will have commercial applicability and success within market and institutional environments. As Breschi and Lissoni (2001) have emphasized, market transactions mediate important forms of university-industry interaction including labor mobility, contract-based research or consultancy, and collaborative projects, as well as spin-offs and third-party licensing of intellectual property. However, the relational content of these forms of engagement means the key role of the market here can, following Potts (2001), equally be interpreted as one of structuring a distributed knowledge system. In addition, these market-based relationships do not cover all means of potential connectivity between universities and industry, which include more informal social interactions and, despite moves in some domains towards the privatization of science, open science channels (Nelson 2004). The contribution of universities to regional innovation systems may also rely less on cooperative networks formed via research activities than on their other major function of educating large numbers of graduate workers employed by local firms (Lambooy 2004). The potential heterogeneity of the agents and links involved therefore suggests a complex adaptive system framework, and supports the alternative thesis that the role of universities in economic evolution needs to be understood through the concept of system self-transformation. High levels of interconnectivity will mean that interactions and feedbacks generated with the production of new knowledge by academic actors can potentially bring about the adaptive co-evolution of multiple other agents throughout the complex system. This evolutionary process may be subject to selection forces at a micro-level, in the form of varying capabilities of individual firms (shaped in-part by their access to regional knowledge bases) to connect with universities and effectively utilize outputs of their research[5]. However, the processes of system self-transformation that particularly feature universities, as argued below, are in important ways driven by dynamics outside this competitive business environment. As complex adaptive system frameworks emphasize openness between hierarchical levels, such as economic sub-systems formed at different spatial scales (Martin and Sunley 2007), the varying geography of local and non-local university-industry linkages identified above can in theory also be accommodated.

This position, while new to economic geography, has previously been articulated by Metcalfe (2010). He argues that "the distinctive worlds of universities and businesses in a modern economy are coupled sub systems of a complex adaptive system, one which transcends national boundaries and is governed by principles of self-organization and adaptive evolution" (p.7). Later he expands:

> the economy and science are not only self organising systems, they are also self transforming systems and there is a great deal of interdependence in the manner of their respective self transformations. ... Moreover, the manner of the respective processes of self transformation is evolutionary in the sense that it is driven by the unexpected emergence of novelty and by the subsequent adaptation of the prevailing order to the challenges immanent in that novelty. (p.12-13).

[5] It will be particularly important to incorporate these selection forces in a complex adaptive system framework to explain the success or failure of efforts at research commercialization (e.g. spin-off firms) when market pressures will most directly act on academic knowledge. As noted above, however, this will only account for a small proportion of academic engagements with industry, and these selection processes will not operate as strongly on the formation of the majority of other connections through which self-transformation in the system occurs.

The self-organizing nature of connections between these sub-systems means that the co-evolutionary adaptive process described here is largely ‘spontaneous’ rather than ‘designed’, and will lead to development of the system along unplanned and emergent development paths (also Lambooy 2004; Viale and Pozzali 2010).

Crucially, this perspective allows the ‘division of labor’ between universities, firms and other organizations that together constitute territorial innovation ecologies to be recognized (Rosenberg and Nelson 1994; David and Metcalfe 2010; Metcalfe 2010). As mentioned above, the commercially-oriented entrepreneurial activities of universities that encourage spin-off firm formation, labor mobility and joint research with industry can be a stimulus to evolutionary processes such as the emergence of knowledge-based clusters. However, focusing on these mechanisms alone risks reducing universities to essentially the same function as firms (i.e. the inter-organizational transmission/inheritance of knowledge or routines) within a Darwinian-based explanatory scheme, thereby disregarding their particular institutional characteristics and distinctive roles within processes of regional innovation and adaptation, which will be the focus of the next section.

Universities in complex adaptive systems

The application of complexity thinking within EEG is still at an early stage, but the notion of organizations being open and adaptive systems has a longer lineage within evolutionary-informed work in economics and management studies (Morgan 2006). The first part of this section will briefly draw on this organizational literature to identify key properties of these adaptive systems and how they may manifest at a regional level. This forms a foundation for the subsequent discussion of how universities can enhance the adaptive capacity of territorial economic entities understood as complex systems. As identifiable economic subsystems can form at different and interacting hierarchal levels in this framework, the argument in this section does not privilege one given scale (i.e. local, regional, national). This is not however to imply that differences in geographical level are irrelevant to evolutionary processes, and the conclusion will return to questions of spatial organization as an issue for future research.

Adaptive capacity

Cyert and March (1963) refer to financial resources received by members of a firm in excess of what is required to maintain the activities of that firm as 'organizational slack'. They argue these resources act as a buffer that "absorbs a substantial share of the potential variability in the firm's environment" and hence "plays both a stabilizing and adaptive role" for the organization (p.43-44). Relating to the adaptive role, they suggest firms with large amounts of this spare capacity will be more capable of supporting forms of innovation that "tend to be difficult to justify in the short run and [only] remotely related to any major organizational problem" (p.189). Later, March (1991) extended this line of thinking by arguing that adaptation through organizational learning is reliant on resources being allocated to activities focused on *exploration* (e.g. search, risk-taking, experimentation, discovery) as well as *exploitation* (e.g. production, refinement, selection, implementation). He summarizes the resulting trade-off:

> Adaptive systems that engage in exploration to the exclusion of exploitation are likely to find that they suffer the costs of experimentation without gaining many of its benefits. They exhibit too many underdeveloped new ideas and too little distinctive competence. Conversely, systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in suboptimal stable equilibria. As a

result, maintaining an appropriate balance between exploration and exploitation is a primary factor in system survival and prosperity. (p.71).

The danger of focusing solely on short-term exploitation has also been recognized in management theory. Here, studies have argued that firms need to balance cost efficiency in their activities against the seemingly counterintuitive requirement to permit complex organizations retention of some non-productive slack (including time and human resources) to create space for experimentation and innovation (Lawson 2001). The development of the concept away from its origins in the economics of the firm has broadened analysis beyond organizational resources to include structural and relational elements of adaptability. For instance, Staber and Sydow (2002) propose that organizational adaptive capacity has three dimensions:

- *multiplexity*, "the number and diversity of relations between actors in organizations or interorganizational networks" (p.414);
- *redundancy*, "usually viewed as resource slack, reflected in the presence of surplus employees, unused productive capacity, overlapping jurisdictions, broad job descriptions, tolerance for mistakes, parallel communication channels, or idle information" (p.416);
- *loose coupling*, which "in organizational and interorganizational systems means that the various units and activities are relatively independent and can adjust to changing demands in different ways and at varying rates" (p.417).

The structural dimensions of multiplexity and loose-coupling here refer respectively to the number/diversity and strength/adaptability of relations within organizational systems. Similar properties of adaptive systems have been reflected in various concepts used in economic geography to explain differing capabilities of regional economies to adjust to changes in their environment. For instance, referring to the strength of relations, Pike *et al.* (2010) (following Grabher and Stark 1997) distinguish between regional *adaptation*, defined as "a movement towards a pre-conceived path in the short run, characterized by strong and tight couplings between social agents in place", and regional *adaptability*, defined as "the dynamic capacity to effect and unfold multiple evolutionary trajectories, through loose and weak couplings between social agents in place, that enhance the overall responsiveness of the system to unforeseen changes" (p.62). While economic geographers have also recognized the importance of diversity within the industrial mix of a region through the concept of related variety (Frenken *et al.* 2007; Neffke *et al.* 2011; Cooke 2012), the different issue of institutional diversity, and how this may contribute to regional adaptability, has not received comparable attention[6]. As Schneiberg (2007) argues, economies include varied organizational forms that represent previous or alternative development paths and contain latent elements that may be recombined as the basis for potential directions of change in the future (see discussion by Martin 2010).

The next sub-section will emphasize the importance of this diversity within territorial innovation systems by arguing that the role of universities in facilitating adaptability should be interpreted as mainly relating to institutional features that are largely distinct from those of other economic agents. This will employ the multidimensional understanding of adaptive capacity outlined above. In particular, because this utilizes a contrast of the more 'exploratory' sector of the economy (exemplified here by universities) to the more 'exploitative' sector (represented by private enterprises) it develops the argument that

[6] A notable exception is Grabher and Stark's (1997) work on post-socialist transition in Eastern Europe. Here they argue that, in the face of near uniform marketization and privatization reforms, "institutional legacies that retard the quick pursuit of immediate successes can be important for keeping open alternative courses of action" (p.534).

universities can, by analogy, be seen as a source of valuable 'slack' in a territorial system (Goddard and Vallance 2013).

Universities and territorial adaptability

Considerable variety also of course exists amongst universities, as well as across other higher education or public research organizations of different types[7]. The discussion in this section will primarily refer to large research-intensive universities as a relatively general form of this extended family of institutions that epitomizes many of the characteristics that can enhance territorial adaptive capacity. This focus is not, however, to indicate that these features are exclusive to this group: identifying the varying roles, capabilities, and relational embeddedness of the multiple higher education and/or public research organizations within a territorial ecology will be an important step in the research agenda outlined in the conclusion.

Research universities have generally developed as large, multidisciplinary institutions for the sciences and arts. This means they house a breadth of expertise across specialized fields and knowledge bases that is unlikely to be matched by any other single actor in a local innovation ecology (Hughes and Kitson 2012). Related to this, these universities typically have a decentralized organizational structure of different academic sub-units, including disciplinary-based departments and more multidisciplinary research centers or institutes, and core administrative functions (e.g. technology transfer offices). The relative independence of these units from one another means that universities have been cited as exhibiting features of loosely-coupled organization (Sporn 1999). The internal (vertical and horizontal) dimensions of this structural quality means that while academic or administrative sub-units are able to

[7] This diversity amongst universities and related organizations itself has an important geographical dimension, as it is structured by historically-formed institutional differences in territorial (most commonly national) higher education and innovation systems.

adapt to changes in their particular environment (for instance by responding to funding opportunities) this action is unlikely to have an effect throughout the whole university. This suggests that, within territorial innovation ecologies, universities should not be understood as monolithic institutional entities, but as a collection of diverse, often only weakly-related distributed capabilities. As each academic unit will have its own distinctive set of external connections with local and non-local actors, depending on the field in which it works and the personal networks of its members, the university overall (and even more various universities and related institutions in the same locality) can be a source of considerable 'multiplexity' within a territorial economy understood as a complex and open adaptive system.

Universities may be strongly-coupled to external organizations they are heavily dependent on for resources (e.g. higher education funding bodies, local hospitals for medical schools), but as in general most funding for academic research still comes from public sources[8], this does not typically apply to the private sector. Therefore, even in fields that may have relatively direct industrial applications (e.g. engineering, design, life sciences), universities can pursue more exploratory forms of research than other institutional actors (including other types of higher education or public research organization). Larger technology-intensive firms may have their own internal R&D capacity, but in most cases this will be focused on research with more certain, shorter term commercial goals than scientific research in universities that operates on longer time-scales (Cowan *et al.* 2009). It is this remove from immediate industrial concerns that means academic research can be a source of the novelty that enables the economy to break with existing development trajectories. For instance, new products in

[8] This is a stylized fact that simplifies a complex and changing situation, but one that is broadly valid. Vincent-Lancrin (2009) shows that, the proportion of funding for academic research coming from government sources, despite generally declining over the past three decades, still accounted for a large majority of the total in almost all OECD countries in 2006 (see table 5.4).

life science industries, despite the considerable time-lags and complexity of the development process involved in ultimately bringing them to market, can often be traced back to specific basic science discoveries in university laboratories (Balconi *et al.* 2010; Mazzucato 2013). Lester (2007), drawing conclusions from a research program of multiple case studies of local industrial transformation, emphasizes that universities or other public research organizations are crucial to the most radical form of structural change in a regional economy – the emergence of a completely new industry. As reflected above, the evidence for this process of university-driven growth has largely been based on leading high-technology districts such as Silicon Valley, Boston, and Cambridge (UK). However, other research has indicated that the basic research function of universities can (in combination with mechanisms to support new firm formation) be a key asset through which mature regions may be able to generate cluster dynamics based on newer technology domains (e.g. ICT, biotechnology, nanotechnology) unrelated to their existing development paths (Trippl and Otto 2009).

In the complexity framework proposed here, this endogenous creation of a new path will represent perhaps the largest possible form of adaptive evolution of a territorial economy, in which the production of new technological knowledge is the catalyst for the emergence of new agents and connections that can fundamentally transform the system. However, its radical nature means that it also represents one of the rarest forms of change, which is limited to growth in certain knowledge-intensive industries. Accordingly, Lester (2007) demonstrates that universities can contribute to other more path-contingent forms of industry transformation, such as the upgrading of the technological base or diversification into new but related industries[9]. A territorial economy will have multiple industry sub-components,

[9] This analysis was drawn upon by Martin and Sunley (2006, p.420) for their proposed typology of new path creation in regional economies.

and therefore combinations of these evolutionary path trajectories may be operating simultaneously to shape its overall adaptation (Belussi and Sedita 2009). Lester (2007) also identifies that these contributions to different processes of industry transformation will involve more varied forms of relation with the local industry base and workforce (e.g. consultancy, contract research, specialist training) than the enterprise focused activities (e.g. spin-off firm formation) emphasized in processes of new path generation. This may therefore entail closer engagement with existing firm problems and needs, but the institutional autonomy of universities from the productive sphere can still be key to them supporting industry upgrading or diversification processes. External loose-coupling means that universities may act as repositories for knowledge capabilities relating to industrial domains that have become less competitively viable, but retain some local evolutionary potential for the emergence of new more technologically advanced 'phoenix industries' (Christopherson 2009). For example, recent studies have highlighted European and American universities in former manufacturing regions with strong engineering faculties that continue to perform research and teaching of value to the local economy long after the heavy industries they initially supported have declined as mass employment sectors (Martinez-Vela and Viljamaa 2007; Whitehurst *et al.* 2008; Treado 2010; Amison and Bailey 2014). Here, the stability of the university as a loosely-coupled institutional form combining mutually supporting education and research functions is an important factor that helps protect this form of 'redundancy' against the competitive pressures of the market environment in which private firms operate and allows it to be retained as a source of diversity within the economic system.

When universities are highly connected within local innovation ecologies they may also shape the ongoing evolution of already-emerged industrial paths. Studies of biotechnology, in particular, have demonstrated that the contribution of academic research to the development of clusters is not limited to the early seeding of new scientific knowledge and spin-off enterprises often identified as key founding events, but that universities form part of complex adaptive systems with the various other organizational actors in this industry (Niosi 2011). For instance, Niosi and Banik (2005) show that universities continue to build network links with spatially proximate firms as local biotechnology systems mature, and that the nature of these links change over time towards more formalized market-based means of technology transfer in a co-evolutionary process. The varying institutional make-up of clusters can also shape this process. In a study comparing two world-leading biotechnology regions, Owen-Smith and Powell (2006) find that although initially more venture capital driven Bay Area and more public sector reliant Boston went on to develop similar dense firm-to-firm network structures, innovation processes within these clusters remained markedly more commercially-oriented (Bay Area) and more exploratory (Boston) respectively. They conclude that in Boston these:

> imprints of evolutionary patterns … are a joint function of institutional roles and particular features that characterize … public sector organizations. In addition to providing stable anchors for networks, universities and hospitals contribute to more open information flows, [and] more expansive innovative trajectories … . In short, [public research organization] involvement is effective precisely because they operate in different environments and under different rules and constraints than their proprietary [firm] partners. (pp.80-81).

This supports the argument being advanced here that the institutional diversity created by universities can enhance territorial system adaptive capacity. A normative implication of this position is that, in contrast to a focus on academic enterprise, more exploratory research activities should be recognized as the medium through which universities make perhaps a greater distinctive contribution to long-run economic development (David and Metcalfe, 2010)[10]. This calls for a more nuanced understanding of the nature of academic research described as 'basic' than forms of scientific enquiry that are defined in opposition to any real-world concern. Rosenberg and Nelson (1994) explain how much basic research performed in universities, particularly in engineering and applied science fields (including medicine), consists of problem-solving and design work that is inherently engaged with and responsive to the development of new technologies and/or the societal usefulness of its outcomes. It still, however, importantly differs from commercially-oriented research and development (that is more effectively performed by industry) in its "search for understanding at a very fundamental level" (p.332), which requires "a certain distance from immediate particular practical applications" (p.336). Stokes (1997) defines this type of activity as 'use-inspired basic research', forming a category that disrupts the dichotomy of pure basic and applied research, and the clear separation of academia and industry as the domains in which these practices are institutionalized. Hence, this understanding helps challenge simplified linear models of innovation as a series of sequential steps undertaken by different actors (see discussion by Balconi *et al.* 2010). Instead, the production and use of research are linked by an ongoing, reciprocal process of myriad network interactions, other forms of indirect or spontaneous connections, and information feedbacks within a complex system, and bring about the co-evolution of its interdependent components (Lemay and Sá 2012).

[10] Indeed, when academics do view their research as having an economic impact, survey results have shown that this is more likely to be a secondary effect of work with a primary goal of contributing to disciplinary knowledge, technological development, or advances in other areas of application such as medicine, renewable energies, or public policy (Goddard and Vallance 2013; Upton *et al.*2014).

These issues have been explored in a literature that examines the economic and societal value, and related case for the public funding of, basic research. Mainstream economics approaches to this question have generally been couched in terms of market failure, in which outputs from investment in research are taken to be freely available public goods (see Pavitt 1991). However, Salter and Martin (2001) identify an alternative set of perspectives that they collectively term evolutionary approaches, due to their consideration of the role of basic research in innovation and technological advance understood as a dynamic, non-equilibrium process (also Metcalfe 1997). These heterodox approaches contend that the public good view "substantially undervalues the extent to which knowledge is embodied in specific researchers and the institutional networks within which they conduct their research" (Salter and Martin 2001, p. 512). Therefore, the crucial benefits of basic research to society are not simply restricted to "increasing the stock of useful knowledge", but include inputs to processes that enhance the capacity of industry to generate innovation; for instance, educating graduate workers, developing new scientific instrumentation and methodologies, forming network relationships with firms, and stimulating the creation of spin-off firms (p.520). In a complexity-informed evolutionary position, these different outcomes from basic research can be considered as restructuring connections between the coupled sub-systems of academia and industry, so that the novelty contained in the production of scientific knowledge can become a source of change in the economy as an adaptive system. This potential connectivity is magnified when scientific research becomes widely accessible through various open channels, meaning that different actors can explore the multiple potential paths created by new knowledge (Nelson 2004). A complementary perspective is outlined by Callon (1994), who argues that scientific knowledge is not intrinsically a public good in the way assumed by economists, but takes the form of heterogeneous elements (e.g. instruments, texts, patents, laboratories, scientists and skilled technicians) inscribed in technoeconomic networks mobilized by users as well as producers of research. However, he believes public funding of research still has an essential economic role, as it supports the continual generation and reconfiguration of these networks in a way that acts as a counterbalance to the private logics of increasing returns and coordination (to reduce costs/uncertainty) that encourage lock-in. In evolutionary terms, therefore, this analysis relates to the interaction between the principles of variety and selection, or within adaptive systems to the balance between exploration and exploitation:

> Science is a public good, which must be preserved at all costs because it is a source of variety. It causes new states of the world to proliferate. … [W]ithout this source of diversity, the market – with its natural propensity to transform science into a commodity – would be ever more doomed to convergence and irreversibility. In the end it would negate itself. (p.418).

A more nuanced understanding of basic research also means that, in contrast to its popular representation as 'curiosity-driven', it is not incompatible with public science that is targeted towards particular policy objectives. In the framework proposed here, this points to the potential influence of the State (most likely at a national level) in structuring the complex skein of connections between the academic and industry sub-systems into certain more ordered arrangements. More generally, recognition of this dynamic corresponds with MacKinnon *et al.* (2009) that the dominant focus in EEG on self-organization through aggregate micro-scale processes needs to be considered alongside "deliberate intervention through public institutions such as the state in shaping the evolution of the economic landscape" (p.136). Here the role of the State is not restricted to its activities as the largest funder of academic research, but should encompass its direct and leading participation, partly operating through networks of public research agencies, in the early development of new strategic technologies that enable innovations in the rest of the economy (Mazzucato 2013). These non-university public technology and innovation centers (with either a national or regional remit) typical focus on specific areas of applied scientific research, and perform an intermediary bridging function in linking academic institutions and firms to build more systemic connections within their innovation ecology (Goddard *et al.* 2012). The reinforcing nature of the role of government and universities in multi-level processes of economic evolution can be seen in Finland (Sotarauta and Srinivas 2006). Here the State, by adopting a policy of increasing resources for R&D and concentrating these into national technology programs focused on the ICT sector, is acknowledged as being the driving force behind the successful creation of a new path for the Finnish economy following an early 1990s recession (Schienstock 2007). Crucially, however, this transformation was preceded by an expansion of the higher education system during the 1960s and 1970s through the establishment of universities in regional cities outside of the south of the country for the first time. The capacity generated by the existence of these institutions and their industry links, as well as contributing to the development of the strong national innovation system, have been recognized as being vital in enabling more local adaptations to the needs of a knowledge-based economy during the 1990s and early 2000s in secondary cities like Tampere (Kostiainen and Sotarauta 2003; Sotarauta and Srinivas 2006; Martinez-Vela and Viljamaa 2007). Local universities also continue to be central actors in efforts to adjust to the more recent structural reform of the economy forced by the decline of Nokia Corporation as the anchor firm for the national ICT sector (Vallance 2015).

Conclusions

This paper has been concerned with developing a more explicit theorization of the contribution of universities to territorial economic change within the emerging field of EEG. This aim presupposes a departure from the predominant focus on populations of firms as economic agents that characterizes the most common EEG approaches informed by generalized Darwinism. Instead, it has been argued that the introduction of universities into EEG supports movement towards analytical frameworks in which the economy is understood as a complex and open adaptive system – that is as a collection of distributed agents of different types that are nevertheless interconnected – and in which the academic sphere is seen as a distinct but coupled sub-system. Accordingly, the potential for universities to support change in a territorial economy derives from their capability to produce new knowledge that, as a source of novelty, brings about endogenous co-evolution and adaptation throughout this complex system. In this perspective, the presence of high levels of connectivity between universities and other economic agents, which enables this systemic self-transformation, is more significant than specific mechanisms of selection through which knowledge generated in universities is commercially validated. Market processes still have an important effect in structuring the connections created through mechanisms such as licensing, the formation and survival/growth of academic spin-off firms, and university-to-industry staff mobility, but as vital is the relational content of other more informal, social-based means of academic engagement, along with 'open science' channels and graduates entering the workforce. In being at least partly removed from the competitive market pressures faced by firms, universities can, with other research institutes and the R&D departments of some large firms, perform the exploratory functions that enhance the overall long-term adaptive capacity of an economy. This highlights distinctive institutional features of research universities that previous studies of their role in regional innovation have not tended to stress: such as their diversity of knowledge bases and decentralized structure, their varied international as well as local and national network connections, and their potential to access public funding for basic scientific activity. The public research and development function performed by universities and related institutions, through which scientific and technological development occurs in society, needs to be accommodated if EEG is to provide a comprehensive explanation of new path creation. This should only be seen as a complementary and interrelated mode of innovation to that performed by firms seeking to develop 'fitter' routines in a competitive environment, but it remains vital as a dynamic within territorial economies that can help offset long-term tendencies towards lock-in to development paths.

The challenge of translating this theoretical agenda into empirical work will need to address considerable methodological issues relating to the operationalization of concepts drawn from complexity theory in the context of studying specific territorial economic entities. However, as a starting point it seems clear that this will involve a broader analytical perspective than the current lines of research discussed earlier, that touch on the role of universities in processes of economic evolution by concentrating on individual means of academic knowledge transfer such as spin-off firms, research collaborations, and labor mobility into firms. Notwithstanding the considerable value of this work, in a complexity theory approach these mechanisms should only be elements of broader case studies which examine, qualitatively and quantitatively, how the varied connectivity of universities have enabled processes of industrial adaptation and co-evolution within wider national or regional economic systems. A concern with universities and other public research organizations should, therefore, not be viewed as a separate line of enquiry in EEG, but incorporated in the larger project of deepening empirical understanding of dynamic and place-contingent processes of path creation. This position therefore endorses the insights from complexity theory outlined here being brought into constructive dialogue with those from other approaches (e.g. innovation systems, generalized Darwinism, geographical political economy) as part of an EEG progressed through 'engaged pluralism' (Hassink *et al.* 2014).

A methodological focus on specific cases of industrial path creation within regional or national economies, whether retrospectively or as they are unfolding, can also act as useful entry point for the substantiation and analysis of the complex, multifaceted processes of change advanced in abstract conceptualizations of economic evolution (Pike *et al. forthcoming*). This means that, in reference to the concerns of this paper, key research question will relate to the changing nature of connectivity and co-evolution between universities and other actors across different stages of local path evolution; for instance, in each of the pre-formation, creation, development, and stasis or further adaptation/mutation phases proposed by Martin (2010). The above emphasis on the generation of novelty through basic research indicates that universities may be particularly crucial in the phases covering the origination of a new path, which is otherwise often attributed to historical accident. However, within the non-linear dynamics of a complex adaptive system framework, it will also be important to understand the ways in which universities remain connected to the development of a maturing path and continue to shape the corresponding structural evolution of the territorial economy. Conversely, economic geographers should also be attentive to the value of studying the opposite (and likely more common) case of when the generation of knowledge through public research does not lead to the creation or significant adaptation of a regional economic path. In reference to attempts at the direct commercialization of research, this may be attributable to the operation of selection mechanisms in a market environment. However, in this complex adaptive systems framework, where evolutionary self-transformation processes are not necessarily dependent on this commercialization, this lack of adaptability will have to be explained through wider institutional factors that may account for low levels of connectivity between universities and firms in the region in question.

The conceptual discussion in this paper raises two further general questions that will only be satisfactorily addressed through empirical work. The first is how the varying potential for universities to enhance adaptive capacity in different regional economies can help meet the need highlighted by Martin and Sunley (2015) for EEG to contribute to explanations of uneven development patterns. In celebrated cases such as Cambridge (UK), the presence of a strong multidisciplinary research university has clearly had a significant impact in helping the cluster to support the successive development of multiple related industrial paths in different scientific/technological fields (Martin 2010). In other regional economies with a less vibrant or diverse ecology, however, despite expectations commonly placed on universities in regional innovation strategies, these effects have not been replicated. This may be a consequence of the research performed in indigenous universities simply not being novel enough to support significant new economic paths, but in peripheral or less developed regions it could also reflect a low density or capability of local firms in knowledge-based industries that means high levels of connectivity with universities needed for processes of co-evolution are unlikely to form. Empirical work will therefore have to be sensitive to both the system of different types of higher education or public research institutions and the wider economic context of the region in question.

Second, a complexity perspective invites perhaps an even more fundamental empirical question of the scales at which universities contribute to processes of territorial adaptation. Localized learning processes in regional institutional environments may still be the prevalent spatial dynamic in this complex system framework (Cooke 2012), but existing lines of research described earlier have demonstrated that academic-industry research collaborations and scientist mobility also form significant interregional and international connections. However, this work has not typically shown how these trans-local relationships support processes of economic adaptation at, and possibly co-evolution between, territorial sub-systems that form at the different scales they help link. This is relevant to the preceding question, as because regions will have varying levels of connectivity into these international academic networks, developments in scientific understanding at a global level will have uneven impacts in terms of stimulating adaptive evolution at a local level.

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